

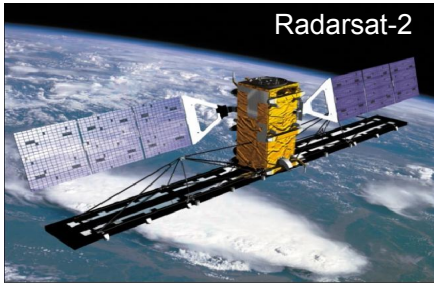


**NOAA**

# The use of Synthetic Aperture Radar (SAR) for Tropical Cyclone Observation

**Christopher R. Jackson**  
**Tyler Ruff**  
**Sean Helfrich**

**2022 Tropical Cyclone Operations  
and Research Forum – March 2022**



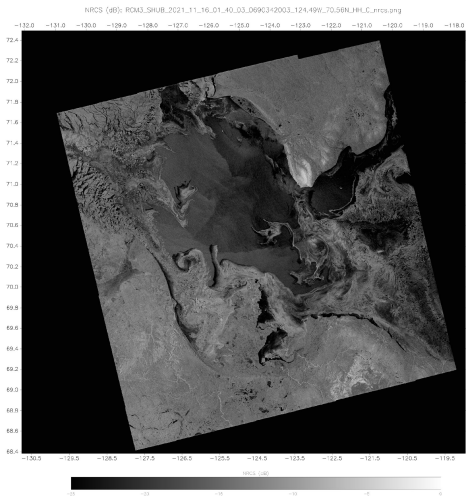
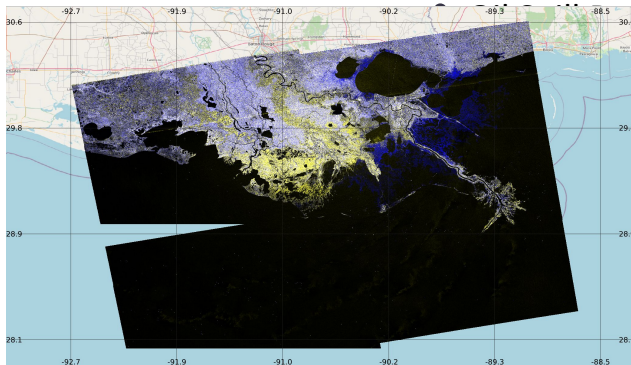
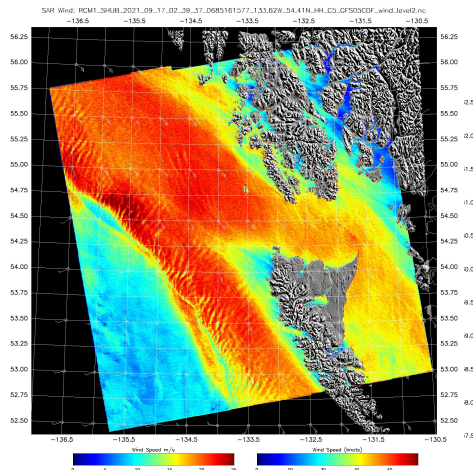
# NOAA STAR Synthetic Aperture Radar Products Team

The Center for **Satellite Applications and Research (STAR)** is the science arm of National Environmental Satellite, Data, and Information Service (NESDIS).

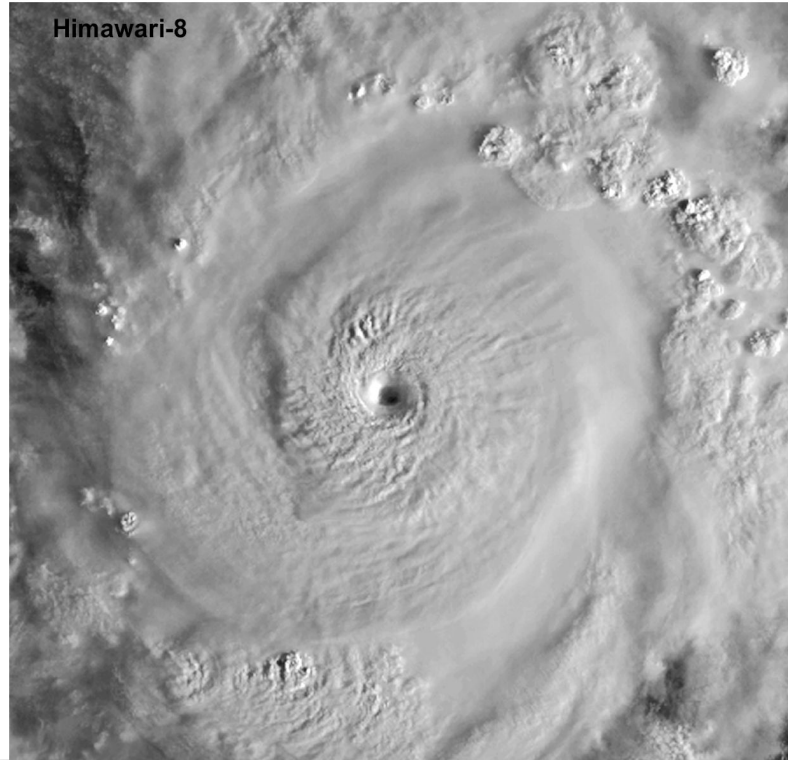
STAR's mission is to accelerate the transfer of satellite observations of the land, atmosphere, ocean, and climate from scientific research and development into routine operations, and offer state-of-the-art data, products, and services to decision-makers.

Synthetic Aperture Radar Products Team has programs to produce

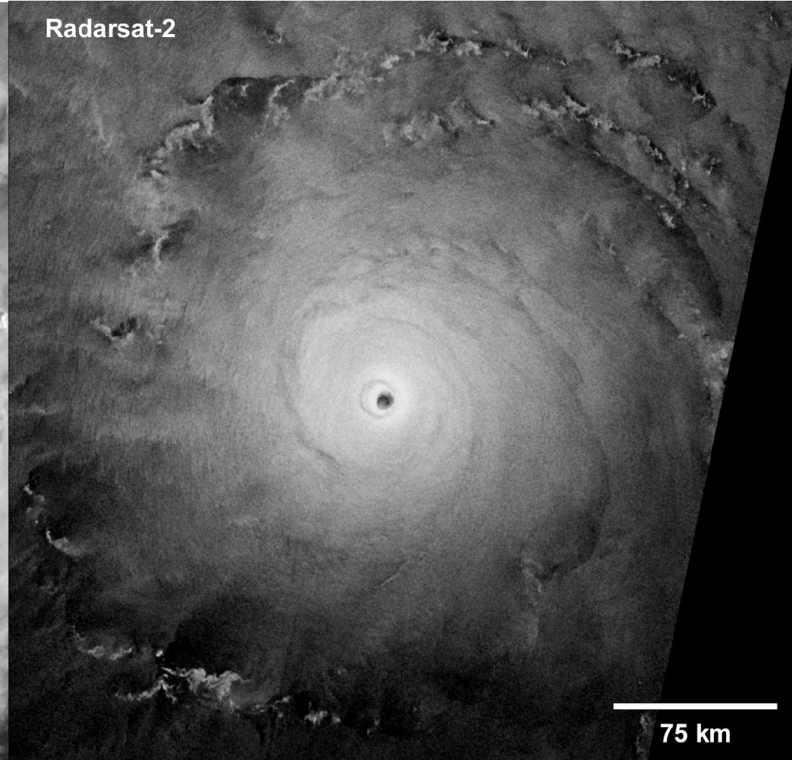
- Ocean Surface Winds Speed
- Tropical Cyclone Wind Speeds
- Flooding and Inundation Maps
- Sea Ice Extent and Characterization
- Great Lakes Ice



# Super Typhoon Goni – 30 Oct 2020



Himawari-8 22:17 UTC Visible Band



Radarsat-2 21:16 UTC Cross-Polarization

# RCM Tropical Cyclone Coverage: Hurricane Linda

NOAA/NESDIS/STAR has in place a fully automated system to produce high resolution near real-time Tropical Cyclone ocean surface wind speed products from SAR

The SAR Tropical Cyclone system currently produces

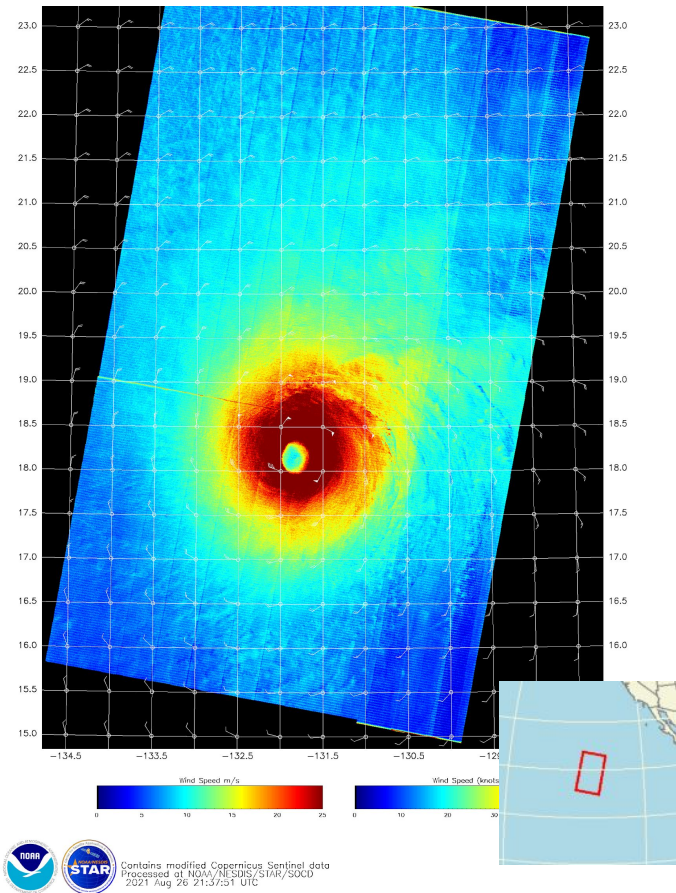
- 500 m and 3 km wind speed images
- Radial wind profiles
- Maximum wind speed and radius of maximum winds
- 34, 50 and 64 knot quadrant fixes
- Eye location and area (when covered).

SAR is the only instrument capable of resolving the fine details (< 500 m) of the wind field around the eye and providing accurate tropical cyclone (>34 kts) winds (at the ocean surface)

Since 2019 NOAA STAR has been providing SAR Tropical Cyclone winds to forecasters at the Joint Typhoon Warning Center (JTWC).

- Good feedback on product utility and packing/delivery

Hurricane Linda (EP122021)  
18 August 2021 14:40 UTC



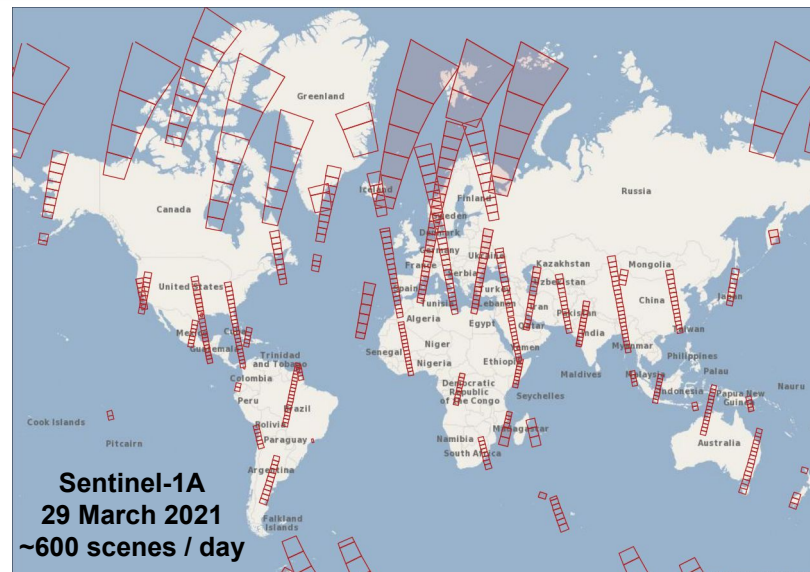


# Sensor Characteristics – SAR and ASCAT



	Radarsat-2	Sentinel-1
Launch	2007	2014 (A) / 2016 (B)
Altitude (km)	798	693
LT Ascending Node	18:00	18:00
Look Direction	Side Looking - Right	
Incidence Angle (deg)	20-49	20-45
Swath Width (km)	50,100,150 <b>300,500</b>	80,240,400

Resolution	<b>50/100 m</b>	<b>40/80 m</b>
Polarization	VV,VH,HH,HV	VV,VH,HH,HV



- Satellite-based SAR acquires data with a limited footprint and only over a portion of every orbit
  - Sentinel-1 collects for 25 min of every orbit resulting in about 600 scenes/day
- All collections are programmed in advance
  - S1 “standard” pattern\*
  - Special collection (TCs, Disaster Charter etc.)

# SAR TC Data Acquisition

---

- Tropical cyclone collection opportunities are identified by comparing forecasted storm tracks against possible SAR acquisition time and footprints.
  - Need to have a storm forecast track
  - The storm must persist for long enough for a collection to be scheduled and acquired
  - The location and timing of the SAR footprint must align with the eye location and track
- Sentinel-1 TC planning is done under Copernicus' Cyclone Monitoring Service (CYMS).
  - Experts at CLS (Collecte Localisation Satellite) and IFREMER coordinate with ESA Mission Planning Team to develop the acquisition schedule and program the satellite's collections.
  - Formal agreement to do planning between IFREMER/CLS and ESA within a dedicated ESA project
  - Monthly collection limits – constrained by current S1 utilization for current collections
- Radarsat-2 (STAR) TC acquisition planning is done by researchers from NOAA STAR (Center for Satellite Applications and Research) in cooperation with its U.S. Government partners and MDA Space
  - The RS-2 imagery are “charged” against a U.S. Government allotment quota.

\*Sentinel-1 as part of its daily “standard collection pattern” does fortuitously acquire tropical cyclone imagery (usually close to land)

Tropical Cyclone collections are programmed 2-5 days in advance.

# SAROPS Tropical Cyclone Winds System

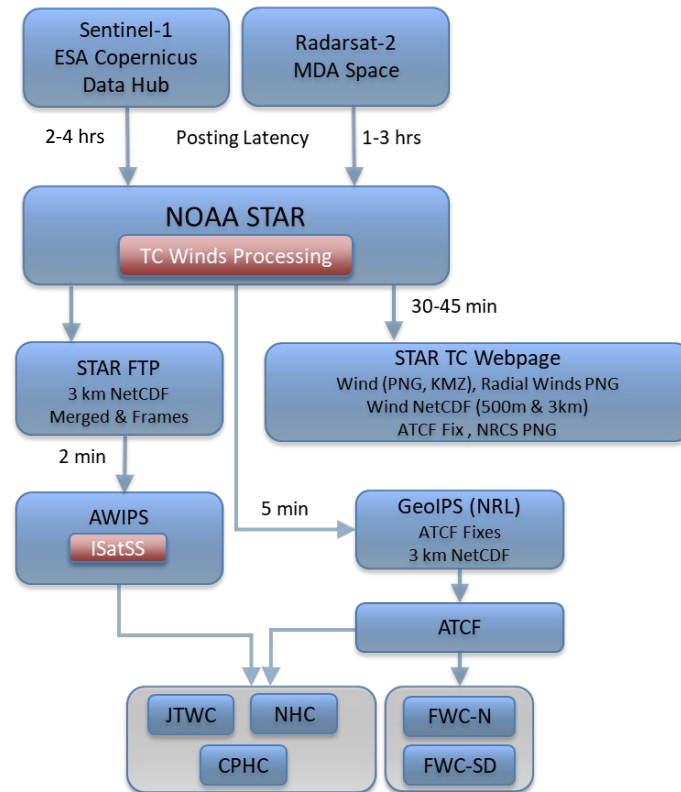
## Automated Data Acquisition

- Sentinel-1
  - Collects global hourly tropical cyclone forecasts (from NHC/JTWC B Deck and NOAA SAB) and checks for corresponding SAR imagery
- Radarsat-2
  - Collection times input into the system based on planning

## SAROPS System Processing

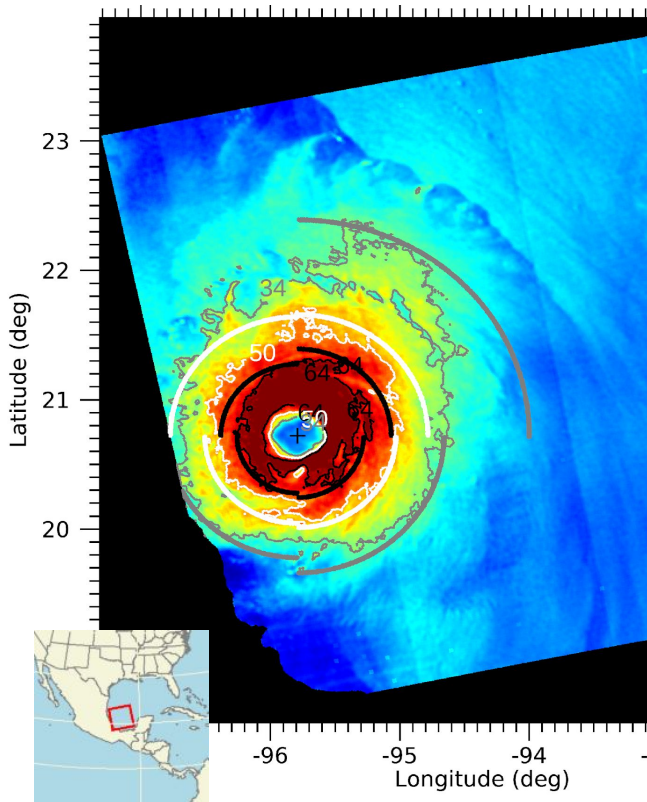
- 1) Produces cross-pol ocean surface wind speeds
- 2) Determines if the storm “eye” is in the scene.
- 3) Produces a refined storm center location
- 4) Produce derived TC specific products (radial wind plots per quadrant, ATCF/radial text files, 3km-sampled wind netCDFs)
- 5) Send to web and push files to ATCF and AWIPS

Latency (faster is better!) < 3 hours



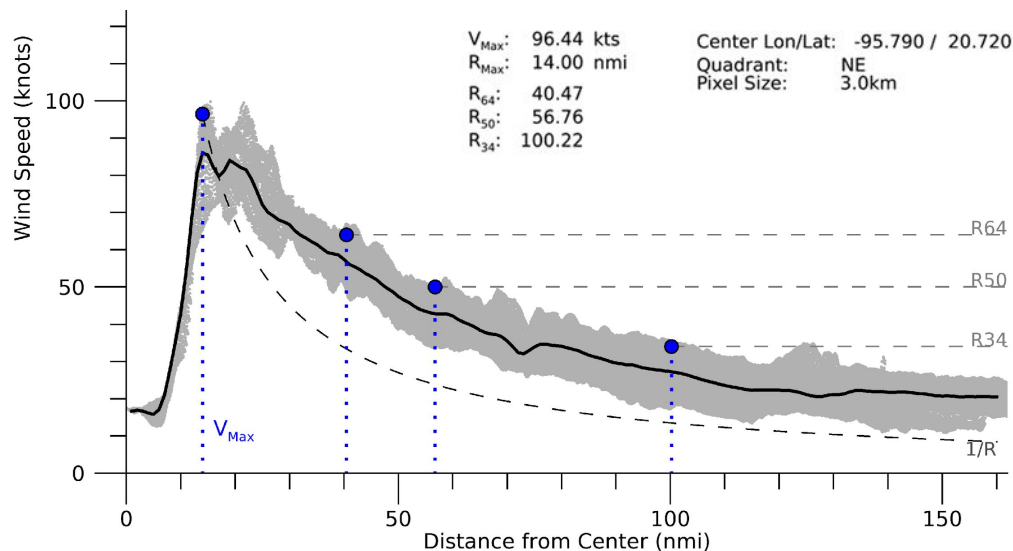
# SAR Derived TC Information Location / Profiles / Fixes

Radarsat-2 (21 Aug 2021 00:22 UTC) Cross-Pol  
AL072021 Grace - 95% Fixes



## Key TC information from SAR

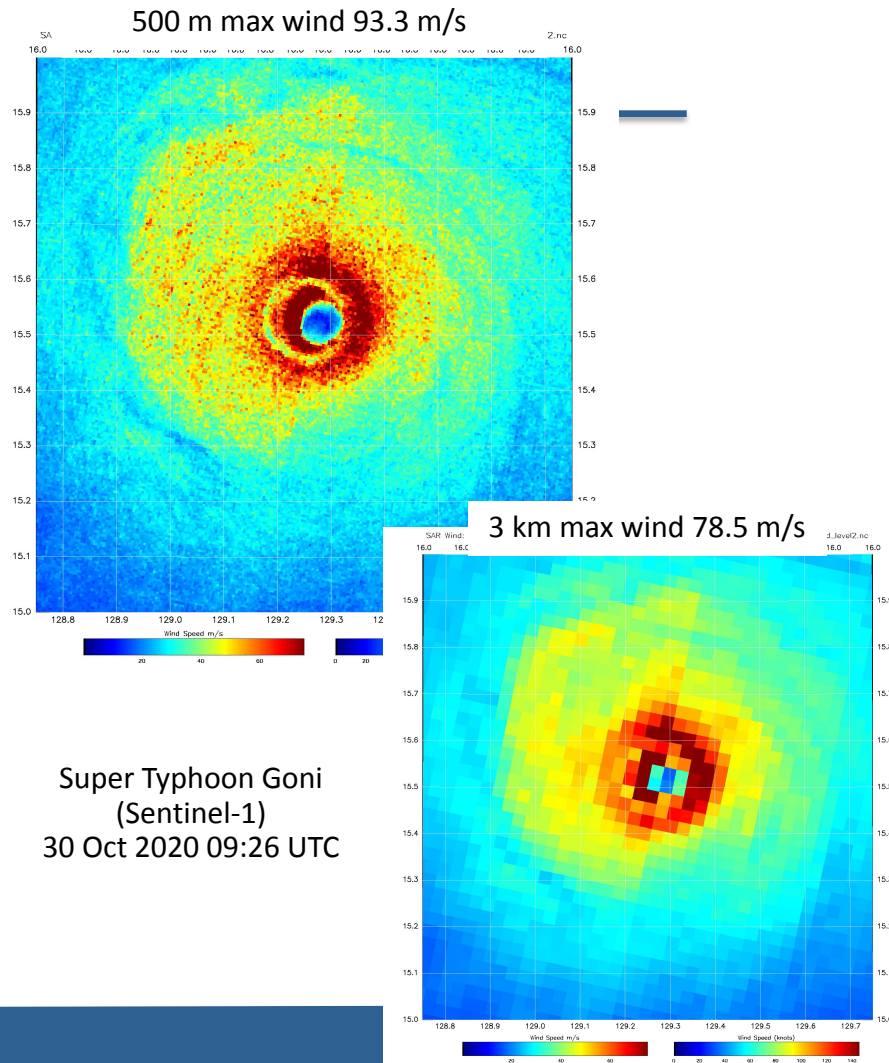
- Identifying the center of circulation (when covered).
- Maximum wind speed and Radius of max winds
- Radial wind profiles (per quadrant 3km sampling)
- 34, 50 and 64 knot quadrant fixes



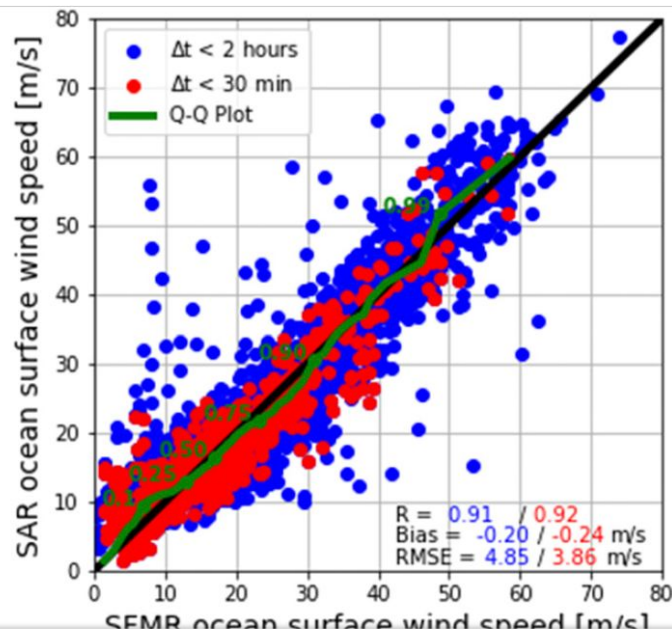


# TC SAR Winds - Overview

- SAR tropical cyclone ocean surface wind speeds are produced by converting the Cross-Polarization (VH or HV) normalized radar cross section (NRCS) backscatter via a specially developed geophysical model function (Mouche et al. 2017)
  - Requires good calibration and noise removal
- The SAR image is essentially an instantaneous snapshot of the surface roughness at < 100m resolution.
  - 500 km wide image is acquired in about 30 sec
- The SAR wind speed (intensity) will be dependent on NRCS spatial averaging used in the GMF.
  - Higher averaging produces lower “maximum” wind speeds
- To produce a “one minute average” SAR wind value the imagery are spatially averaged to 3 km
  - 50 m/s x 60 sec = 3 km (“Mean” storm wind speed x 1 minute)



# SAR Cross-Pol Winds – Validation (What is Truth?)



Extensive High-Resolution Synthetic Aperture Radar (SAR) Data Analysis of Tropical Cyclones: Comparisons with SFMR Flights and Best Track

CLEMENT COMBOT,<sup>a</sup> ALEXIS MOUCHE,<sup>a</sup> JOHN KNAFF,<sup>b</sup> YILI ZHAO,<sup>a</sup> YUAN ZHAO,<sup>a</sup> LEO VINOUR,<sup>a</sup> YVES OUILLEN,<sup>a</sup> AND BERTRAND CHAPRON<sup>a</sup>

2020 Monthly Weather Review, 148(11), 4545-4563.

- Significant work has been done to validate the C-Band cross-polarization GMF
  - Mouche et al. 2019, Combot et al. 2020
- Combot et al. compared 29 SFMR / SAR winds from 13 storms between 2015 and 2018 (23 Atlantic and 6 Pacific)

SAR / SFMR Winds

Bias = -0.24 m/s

RMSE=3.86 m/s

- These number are comparable to SFMR / SMAP comparisons
  - Bias 0.64 m/s and Std Dev 3.11 m/s Collections / 5 storms) (8)
  - Meissner, Ricciardulli and Wentz - 2017 Bulletin of the American Meteorological Society, 98(8), 1660-1677
  - SMAP resolution 40 km

# SAROPS Tropical Cyclone Winds System

**STAR — Center for Satellite Applications and Research**

formerly ORA — Office of Research and Applications



[AKDEMO Home](#) • [SAR Products](#)

## SAROPS Tropical Cyclone Winds

Note to users: This webpage is continuously being updated and results should be considered preliminary. [Click here for more information.](#)

All Latest 2021 2020 2019 2018 2017 2015 Search all storms

2021

Atlantic (1) Central Pacific (0) Eastern Pacific (3) North Indian Ocean (1) Southern Hemisphere (13) Western Pacific (3)

[IO012021 / TAUKEAE \(2021\)](#)

Latest scene: 2021-05-18 13:19:23 UTC

[RSAT2 - VH | 2021-05-17 1:02:39 UTC](#)



Download files:

[Info](#)

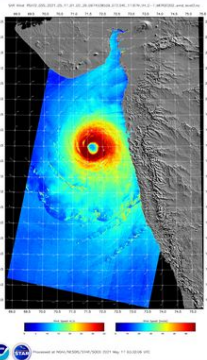
[PNG](#)

[KMZ](#)

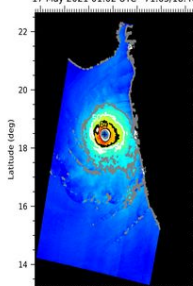
[NRCs](#)

[netCDF 500m / 3km](#)

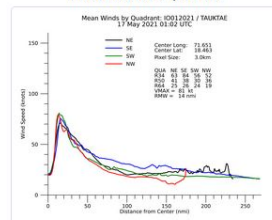
[ATCF / Radial Winds](#)



SAR Wind Speeds: IO012021 / TAUKEAE  
17 May 2021 01:02 UTC 71.65/18.46

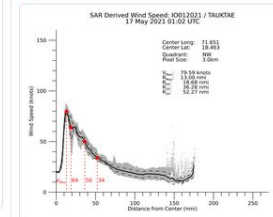


### Mean Winds by 4 Quadrants

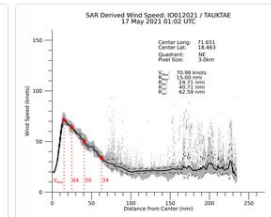


### Radial Winds by Quadrant

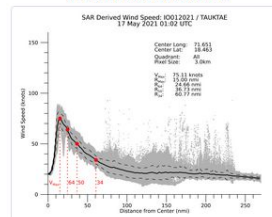
NW



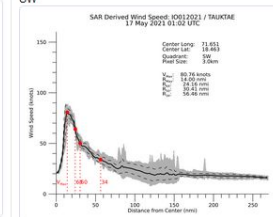
NE



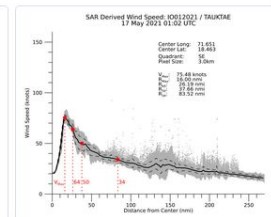
### Radial Winds for All Quadrants



SW



SE



### All Storm Scenes

S1A - VH

2021-05-16  
1:03:39 UTC



MERGED02 Info PNG KMZ NRCs netCDF 500m/3km C-7:

RSAT2 - VH

2021-05-17  
1:02:39 UTC



MERGED02 Info PNG KMZ NRCs netCDF 500m/3km C-7:

S1A - VH

2021-05-18  
13:19:23 UTC



MERGED01 Info PNG KMZ NRCs netCDF 500m/3km C-7:



MERGED01 Info PNG KMZ NRCs netCDF 500m/3km C-7:

[https://www.star.nesdis.noaa.gov/socd/mech/sar/AKDEMO\\_products/APL\\_winds/tropical/index.html](https://www.star.nesdis.noaa.gov/socd/mech/sar/AKDEMO_products/APL_winds/tropical/index.html)

# SAR TC Acquisitions 2020 and 2021

## 2021

Atlantic	Central Pacific	Eastern Pacific	North Indian Ocean	Southern Hemisphere	Western Pacific
<a href="#">AL052021 / ELSA</a> <a href="#">AL072021 / GRACE</a> <a href="#">AL082021 / HENRI</a> <a href="#">AL092021 / IDA</a> <a href="#">AL122021 / LARRY</a> <a href="#">AL142021 / NICHOLAS</a> <a href="#">AL152021 / ODETTE</a> <a href="#">AL162021 / PETER</a> <a href="#">AL182021 / SAM</a> <a href="#">AL202021 / VICTOR</a> <a href="#">AL212021 / WANDA</a>	No storms available	<a href="#">EP042021 / DOLORES</a> <a href="#">EP052021 / ENRIQUE</a> <a href="#">EP062021 / FELICIA</a> <a href="#">EP122021 / LINDA</a> <a href="#">EP142021 / NORA</a> <a href="#">EP152021 / OLAF</a> <a href="#">EP162021 / PAMELA</a> <a href="#">EP172021 / RICK</a>	<a href="#">IO012021 / TAUKEA</a> <a href="#">IO032021 / SHAHEEN-GU</a>	<a href="#">SH052021 / YASA</a> <a href="#">SH062021 / ZAZU</a> <a href="#">SH072021 / CHALANE</a> <a href="#">SH122021 / ELOISE</a> <a href="#">SH152021 / ANA</a> <a href="#">SH192021 / FARAJI</a> <a href="#">SH212021 / GUAMBE</a> <a href="#">SH222021 / MARIAN</a> <a href="#">SH232021 / NIRAN</a> <a href="#">SH242021 / HABANA</a> <a href="#">SH252021 / IMAN</a> <a href="#">SH262021 / SEROJA</a> <a href="#">SH292021 / JOBO</a>	<a href="#">WP022021 / SURIGAE</a> <a href="#">WP062021 / CHAMPI</a> <a href="#">WP092021 / IN-FA</a> <a href="#">WP132021 / LUPIT</a> <a href="#">WP182021 / CONSON</a> <a href="#">WP192021 / CHANTHU</a> <a href="#">WP202021 / MINDULLE</a> <a href="#">WP242021 / KOMPASU</a> <a href="#">WP252021 / MALOU</a>

## 2020

Atlantic	Central Pacific	Eastern Pacific	North Indian Ocean	Southern Hemisphere	Western Pacific
<a href="#">AL082020 / HANNA</a> <a href="#">AL092020 / ISAIAS</a> <a href="#">AL132020 / LAURA</a> <a href="#">AL162020 / NANA</a> <a href="#">AL172020 / PAULETTE</a> <a href="#">AL192020 / SALLY</a> <a href="#">AL202020 / TEDDY</a> <a href="#">AL222020 / BETA</a> <a href="#">AL242020 / ALPHA</a> <a href="#">AL262020 / DELTA</a> <a href="#">AL272020 / EPSILON</a> <a href="#">AL282020 / ZETA</a> <a href="#">AL292020 / ETA</a>	No storms available	<a href="#">EP082020 / DOUGLAS</a> <a href="#">EP122020 / GENEVIEVE</a> <a href="#">EP182020 / MARIE</a>	<a href="#">IO012020 / AMPHAN</a>	<a href="#">SH022020 / BELNA</a> <a href="#">SH052020 / CALVINIA</a> <a href="#">SH082020 / TINQ</a> <a href="#">SH132020 / FRANCISCO</a> <a href="#">SH222020 / HEROLD</a> <a href="#">SH232020 / GRETTEL</a> <a href="#">SH252020 / HAROLD</a>	<a href="#">WP032020 / HAGUPIT</a> <a href="#">WP082020 / HIGOS</a> <a href="#">WP092020 / BAWI</a> <a href="#">WP102020 / MAYSACK</a> <a href="#">WP112020 / HAISHEN</a> <a href="#">WP162020 / CHAN-HOM</a> <a href="#">WP192020 / SAUDEL</a> <a href="#">WP212020 / MOLAVE</a> <a href="#">WP222020 / GONI</a> <a href="#">WP232020 / ATSANI</a> <a href="#">WP252020 / VAMCO</a>

## Overview

Season	Cyclones	# Dates	# Eye Hits
2020	35	102	58
2021	43	133	74

## Frame Count

Year	Sentinel-1	RadarSat-2	RCM
2020	196	37	0
2021	209	50	19



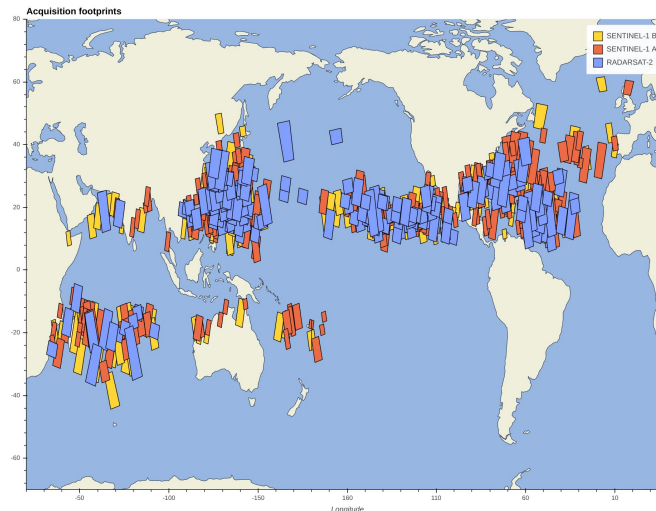
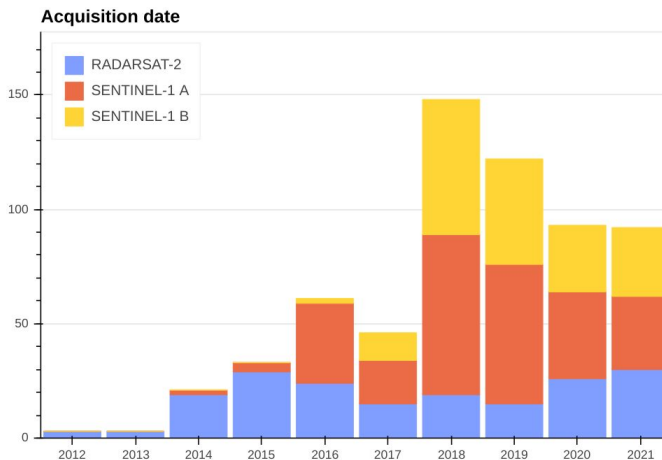
# CYMS Tropical Cyclone Winds Archive

About 100 scenes over  
TC collected per year

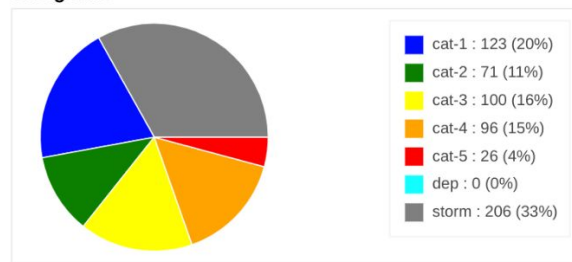
Worldwide coverage

Equal contribution from  
the 3 sensors

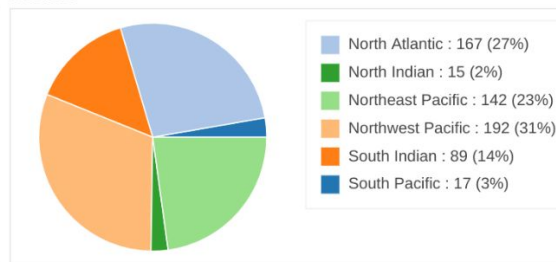
All TC category are  
sampled.



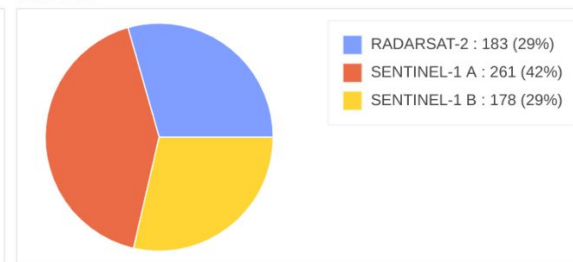
Categories



Basins

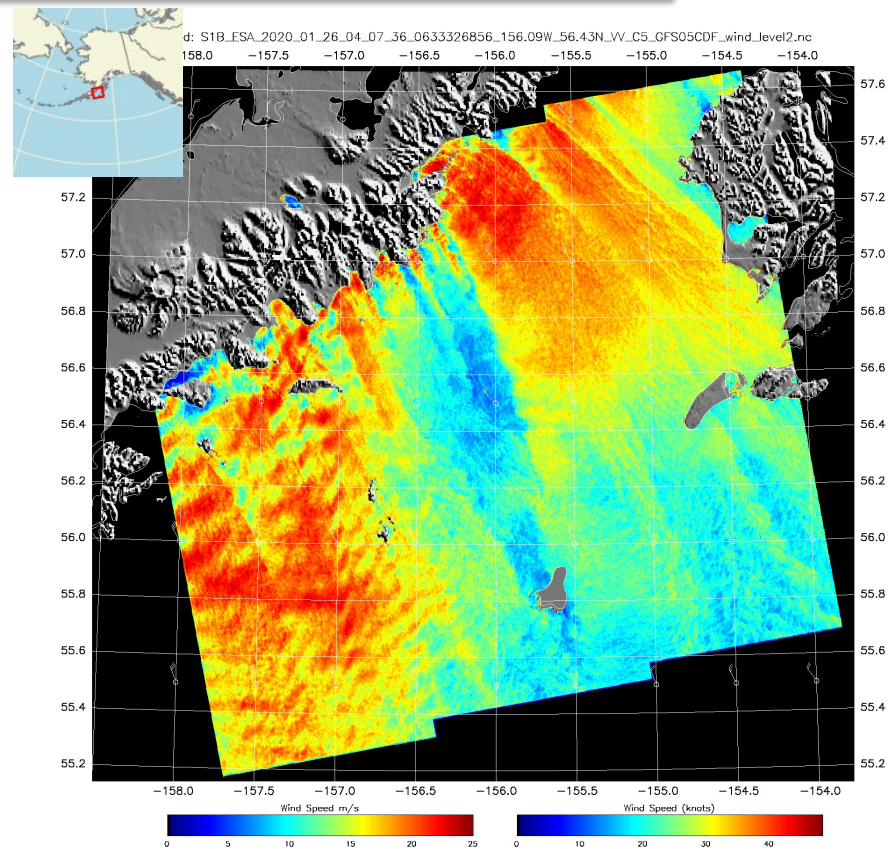


Sensors



# SAR Derived Ocean Surface Winds (Core Product)

- Tropical Cyclone winds products are a specific example of the more general SAR based ocean surface winds effort at STAR and OSPO
  - SAR winds was brought to OSPO operations in 2014 with Radarsat-2 and expanded in 2016 with Sentinel
- The OSPO AOI covers the U.S. EEZ (including Alaska, Hawaii and U.S. Territories) as well as the Caribbean and the North Atlantic
  - Near Real Time with 4-10 hours latency
  - Winds extend right up to the coastlines
  - Products in NetCDF, PNG, KMZ format
- Goal is to get all the WFO's to use these data
  - Working with TOWR-S to make a standard feature in AWIPS
  - Interest from Alaska, American Samoa, OPC
- In March 2021 NOAA obtained access to the data from Radarsat Constellation Mission (RCM) which improved (daily) coverage of area around Alaska, the North Pacific and North Atlantic



Sentinel 1A SAR Co-Pol Winds  
26 January 2020 04:07 UTC

# Final Notes

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- There is an email distribution list to inform users when a new SAR TC collection has been planned
  - Pass along contact information if interested
- Additional satellites coming online will help improved coverage.
  - Radarsat Constellation Mission (RCM)
  - Sentinel-1C (2022)
  - NASA NISAR (2023)
- Be glad to have follow-up meeting to further discuss various SAR coverage/ product / delivery details or to provide a seminar/training

POC: Christoher.Jackson@noaa.gov

# Thank You

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## Eos *Science News by AGU*

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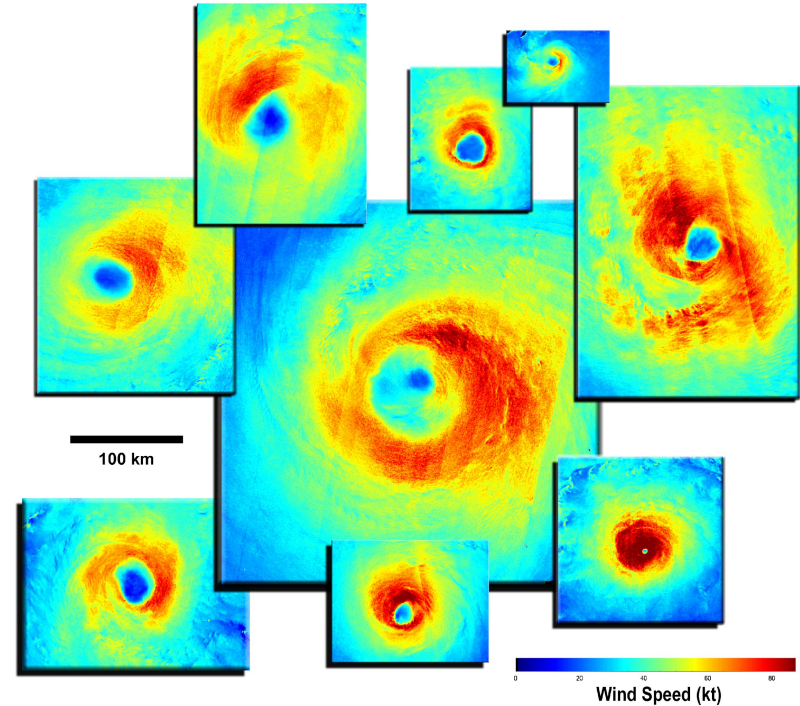
NEWS ▾ OPINIONS ▾ SPECIAL TOPICS NEWS FROM AGU JOURNALS ▾ TOPICS & DISCIPLINES ▾ BLOGS JOBS

NATURAL HAZARDS Feature

### Chasing Cyclones from Space

The pioneering use of satellite-based synthetic aperture radar to characterize tropical cyclones in near-real time has provided a crucial new tool with which to forecast powerful storms.

By Christopher R. Jackson, Tyler W. Ruff, John A. Knaff, Alexis Mouche, and Charles R. Sampson © 2 June 2021



EOS paper: <https://eos.org/features/chasing-cyclones-from-space>



# Other Resources

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## **STAR Tropical**

[www.star.nesdis.noaa.gov/socd/meceb/sar/AKDEMO\\_products/APL\\_winds/tropical/index.html](http://www.star.nesdis.noaa.gov/socd/meceb/sar/AKDEMO_products/APL_winds/tropical/index.html)

## **STAR S1 Winds**

[www.star.nesdis.noaa.gov/socd/meceb/sar/AKDEMO\\_products/APL\\_winds/wind\\_images2/sarwinds\\_daily\\_rcs.html](http://www.star.nesdis.noaa.gov/socd/meceb/sar/AKDEMO_products/APL_winds/wind_images2/sarwinds_daily_rcs.html)

## **STAR Radarsat-2/RCM Winds**

[www.star.nesdis.noaa.gov/socd/meceb/sar/AKDEMO\\_products/APL\\_winds/wind\\_images\\_nic/sarwinds\\_daily\\_now.html](http://www.star.nesdis.noaa.gov/socd/meceb/sar/AKDEMO_products/APL_winds/wind_images_nic/sarwinds_daily_now.html)

## **OSPO RS2/S1 Winds**

[www.ospo.noaa.gov/Products/ocean/sar/index.html](http://www.ospo.noaa.gov/Products/ocean/sar/index.html)

## **ESA Copernicus Scihub**

<https://scihub.copernicus.eu/dhus/#/home>

## **EODMS**

<https://www.eodms-sgdot.nrcan-rncan.gc.ca/index-en.html>

## **CyclObs**

<https://cyclobs.ifremer.fr/app/>

## **NOAA Satellite Book Club Briefing**

<https://www.youtube.com/watch?v=u-sUuLxCpho&t=3s>